An Update on Deep Mixing Technology Worldwide

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Abstract

The authors have recently completed the first part of a two-part report on the Deep Mixing Method. The first volume deals with the chronology of evolution, applications, classification of the various methods, the international market, and possible links to expansion in the U.S. The second volume, due later in 1999, is to deal with treated soil properties and QA/QC issues. This paper provides a synopsis of the first volume.

Background

The Federal Highway Administration (FHWA) commissioned a global state of practice review from the authors following the Tokyo Conference on Deep Mixing and Jet Grouting in May 1996. That conference may be judged by our profession in retrospect to be one of the more significant expressions of technical knowledge on a narrow range of subjects to have impacted current and future U.S. specialty geotechnical construction practice. Not only were the historical leaders of technology from Japan and Scandinavia present, but there was a significant proportion of attendees from North America and Europe to ensure that the rich volume of data openly presented would have a global impact in specialty geotechnical engineering circles. For the first time, these specialists communicated freely and openly in the English language about retrospective, introspective and prospective aspects of the industry. This was particularly welcome from the Japanese and Scandinavian practitioners, whose fundamental and excellent research and development findings had hitherto been available largely in their native language. For example, Terashi (1997) reported over 200 technical papers on Deep Mixing Method (DMM) were published each year in the Japanese language alone, so rendering their contents beyond the scope of occidental readers.

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In the United States, there is a rapidly growing demand in a variety of markets for the benefits that DMM can provide. Mass ground treatment schemes in Boston, MA for tunneling, can be compared with earth retention projects in Milwaukee, WI, seismic retrofits for dams in the Rockies, and deep foundation systems in the San Francisco Bay Area with respect to variety, intensity and technological ingenuity. Yang (1997), provided an informed and comprehensive review.

Most recently, the University of Wisconsin, Milwaukee has started to offer a short course on DMM, at which the leading users and practitioners in the country share their knowledge - and compare their skills - with their peers, while deep mixing specialists are increasingly represented at ASCE GeoInstitute conferences (e.g., Logan, 1997; and Boston, 1998) both as exhibitors and authors. The Deep Foundations Institute has, as of October 1998, established a Deep Mixing Subcommittee, one of whose goals is to establish technical links with the major national and trade organizations worldwide. National groups are hosting specialty conferences, such as the Swedes in October, 1999 in Stockholm.

In the face of this exponential growth of knowledge, technology, and applications, it is timely that the first part of the FHWA state of practice should emerge. It attempts to provide a summary of the technology as it enters the next century. This paper provides a brief synopsis, which should supplement and update the authors' previous overview on the subject (Bruce et al., 1998a and b). The paper follows the same structure as the FHWA Report but focuses only on the more recent developments. A second FHWA-sponsored volume, dealing with treated soil properties and QA/QC issues, is scheduled for later in 1999.

Scope and Definition

DMM remains an in situ soil treatment technology whereby the soil is blended with cementitious and or other materials, either in dry or wet (slurry grout) form. The greatest amount of the work conducted globally involves vertical penetration by one or a number of mixing shafts to create discrete columns or panels. Depending on the application, these elements may be constructed to overlap to provide a variety of geometries of treated soil. The FHWA study addresses only these vertical, rotary methods.

However, there are an increasing number of methods under development which create either mass treatment by using inclined auger or conveyor technology or by using vertical beams with lateral jetting capabilities to provide thin, but continuous in situ membranes. Such applications mainly serve the environmental market - containment fixation, and retention, respectively - and are typically viable to relatively shallow depths (10m). Nevertheless, future studies of DMM should entertain these methods alongside our conventional groups of methodologies.

Historical Evolution

The FHWA study listed some 82 events considered significant in the growth of DMM since the original U.S. concept in 1954, and the independent Japanese and Scandinavian exploitations in 1967. Most of these key events have occurred in the last decade, emphasizing the ever increasing rate of development by contractors, consultants, and owners - including federal agencies in the case of Japan, China, France, Sweden, and Finland. This theme is revisited in later sections.

Another mark of the significance of deep mixing as an engineering tool worthy of retrospective study is the series of reviews by Porbaha and coworkers (1998 a and b), sponsored by the Science and Technology Agency of Japan which closely detail both commercial and research progressions in these last 25 years.

Applications

The main groups of applications remain:

- Hydraulic cutoff walls
- Excavation support walls
- Ground treatment
- Liquefaction mitigation
- In situ reinforcement, piles and gravity walls
- Environmental remediation.

Globally, the novelty now arises when local methods are used for new applications, or when established methods are used in new geographic areas, often by contractors who are seeking to develop their own variant of the method in response to a particular project's challenges. Thus we may anticipate in the next decade's technical press a plethora of case histories dealing with environmental and liquefaction mitigation, and in situ earth reinforcement from practitioners in countries as diverse as the U.K., Indonesia, and Australia, based on the authors' current project awareness.

The viability, both technically and commercially of DMM in its various potential applications and settings will continue to be challenged by solutions based on other technologies and cultural preferences, and rightly so: deep mixing is not the panacea for all specialty geotechnical problems. However, when the goal is ground treatment, improvement or retention, the ground and site are relatively unobstructed, and the depth is limited to about 40m, then deep mixing will most probably be a viable option in countries with easy commercial access to the technology.

Classification of Methods

A total of 24 different methods - mostly fully operational and patented - were identified by the FHWA survey (Figure 1). The classification adopted is based on the nature of the "binder" (grout, or dry); the method of soil blending (rotary alone, or rotary with jet assistance); and the location at which most of the soil/binder blending occurs (along the shaft of a long auger, or only at the mixing tool located at the end of a rod). This classification, of course, only applies to those deep mixing systems employing vertical mixing principles (as discussed above). A new "arm" to this classification will be necessary to accommodate the "mass", or "lateral jetting" variants.

The authors have received peer reviews of this proposed classification from specialists worldwide, and have monitored global practice for three years to date. The generic classification of Figure 1 has in patent terms, "satisfied" these challenges, and so is considered appropriate.

Regarding the future, the constructional developmental trends are towards improving the quality of the mixing process (e.g., Systems 11 and 12); using less expensive binder components (e.g., System 6-FGC); obtaining larger diameter of treatment via jet assistance (e.g., Systems 18 and 21); and improving the level of computer assisted control (most systems, but especially in the U.S., Systems 3, 20, 23, and 24).

International Perspective

In the United States, the authors found 11 contractors who execute, or have the resources to execute, DMM. One group, comprising Condon-Johnson Associates, GeoCon, Hayward Baker, Inquip Associates, Millgard Corporation, and Terra Constructors, are essentially U.S. owned, offer other geotechnical and/or environmental services, and appear to have no involvement in, or dependency upon, foreign resources or licenses. The second group, including Raito, SCC Technology, SMW Seiko, Stabilator USA and Trevi ICOS, are either wholly owned U.S. subsidiaries of foreign companies, or operate only and exclusively under foreign license in the U.S. These companies offer the variants shown against their names in Figure 1.

Following first use in 1986, it has only been since 1992 that DMM has achieved national prominence, with most contractors offering services only since the mid 1990s. It is estimated that the annual volume of DMM conducted for geotechnical applications is currently running between $50 and 80 million with the bulk of the work being conducted in Boston, and the San Francisco Bay Area. The annual market for environmental applications is around $20 million, and unlike the faster growing geotechnical market potential, is growing at only 5 to 10 percent per annum. These estimates are based on interviews with practitioners country-wide.

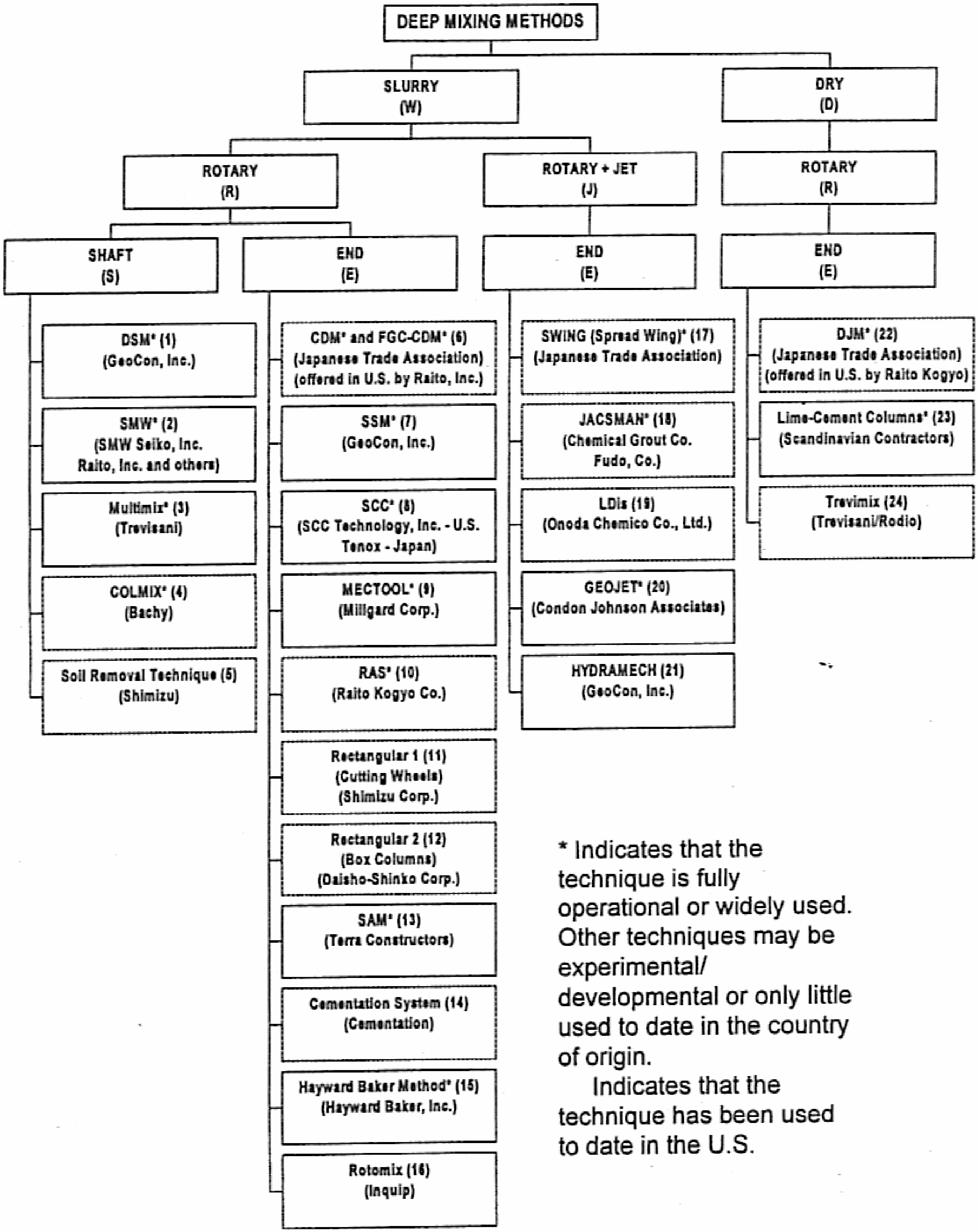

Figure 1. Classification of Deep Mixing Methods based on "binder" (Wet/Dry); penetration/mixing principle (Rotary/Jet); and location of mixing action (Shaft/End).

The level of DMM activity in Japan remains by far the highest in the world. Building upon the Government-sponsored research work in 1967, full scale DMM systems have been used commercially since 1974, and appear to have grown especially quickly in annual volume since the early 1980s. The Japanese contractors, in close cooperation with the Federal Government, manufacturers, suppliers and consultants have continued to develop and enhance DMM technology in response to technical and commercial challenges. Trade associations, often comprising dozens of members, serve the technologies of CDM, DJM, SWING, and Mixed Walls, for example. These associations organize annual conferences and collect and publish data on market volume: a service not yet available in the U.S. Data on annual volumes of ground treated were published by Bruce et al. (1998) from which it may be inferred that the annual DMM volume in Japan is valued at $250 to 500 million, most of it related directly to seismic mitigation.

Activity is increasing in China, especially for harbor and port development at estuarine cities, and has traditionally involved Japanese input. DMM has also been used elsewhere in S.E. Asia, including Taiwan (Liao et al., 1992) and Hong Kong. The total regional market outside of Japan is smaller than in Japan, but exact figures are not readily available.

Like the Japanese, the Swedes began researching in 1967 via a series of laboratory and field tests. The original coworkers included the Swedish Geotechnical Institute, private consultants, and piling companies. This cooperative model has endured, and a wealth of information has been generated about the technical and commercial aspects of the Lime Cement column method in Sweden, and more recently by similar groups in Finland. Their focus remains on ground improvement and pile/soil interaction solutions for very soft, highly compressible clayey and/or organic soils. Therefore, and again in contrast with typical Japanese and U.S. practice, relatively light and mobile equipment has been developed producing single columns only up to 0.8m in diameter, to relatively shallow depths (typically not more than 25m) and with low unconfined compressive strengths (0.15-0.20 MPa).

Market growth has been particularly rapid since 1989 in both countries where the combined volume is around $30 to 40 million annually. Contractors from Sweden and Finland are also active in other countries including Norway, the Baltic States, Holland, U.K., and Hong Kong (in addition to one company in the U.S.) The region's commitment to DMM development is clearly underlined by the formation, in Sweden, of the Deep Stabilization Research Center, and in Finland, a National Structures Research Programme, both in 1995. In each case, national resources have been assembled - similar to the Japanese model - and the findings are to be published in 2000 and 2001, respectively.

Notwithstanding the benefits and advantages which contemporary DMM techniques can offer, there remain a number of factors, often interrelated, which act as potential barriers to market entry for prospective contractors, and/or controls over market growth. These include:

- Demand for the product: given the national trends towards urban construction and redevelopment, seismic retrofit and environmental clear up - all challenges to be solved in situ - then demand for DMM will continue to increase.
- Awareness of the product: a wider range of active specialty contractors and consultants, more prolific technical publications, short courses and the coincidence of several high profile DMM projects nationwide have combined to elevate awareness of DMM in general engineering circles, and will so continue to increase demand.
- Bidding methods/responsibility for performance: the authors believe that the interests of a rapidly developing and complex technology like DMM in the U.S. are best served by "design-build" concepts. Thus, the rate of growth of DMM will be influenced strongly by the rate at which innovative contract procurement and administration vehicles are adopted nationwide.
- Geotechnical limitations: DMM has been developed to treat relatively soft, unobstructed soils and fills in sites with good access. There are other practical limitations as to depth, strength, and durability of the treatment. Extreme care should be taken not to overextend the limits of DMM capability without due regard to a true appreciation of the fundamentals of its evolution. Otherwise, inappropriately applied, designed, and constructed work will lead to owner disappointment, or worse.
- Technology protection: most of the 24 methods show on <u>Figure 1</u> are protected in their technology by Patent or similar. Thus new potential contractors must either invent their own system, or acquire a foreign license. The latter seems more realistic, given the timetables and costs involved in conducting basic research and development.
- Capital cost of startup: given the high levels of technical sophistication, and large physical scale of most systems, startup costs are high. In addition, the larger projects may require several machines and so committed capital expenditures may easily rise to several million dollars. The equipment must also be regularly maintained and upgraded leading to the general conclusion that DMM is a "cash hungry" technology for the contractors who offer it - although the potential return on investment is high. Thus, the field of potential contractors is practically limited by the levels of their own financial resources.

Final Remarks

The many different types of DMM continue to undergo major developments and have experienced notable international success for over two decades. These techniques have rightly become trusted, valuable, and competitive engineering tools for treating, improving, and retaining soils in a wide range of applications.

However, to maintain the rapid growth of the last ten years, DMM must continue to be applied appropriately, designed correctly, constructed efficiently, and restricted sensibly to the natural restraints of soil conditions and mechanical capability. Despite its market potential, it remains relatively costly for contractors to acquire, and so the number of potential competitors will probably remain relatively small. Following this logic, the authors conclude that DMM may well become a commodity product - but a product which can be provided only by a relatively small number of producers. The comparison with the circumstances of the petroleum industry is clear, but with the positive observation that the reserves of the DMM producers are not, in the fundamental sense, finite.

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